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HYPERVELOCITY TRACK TESTS OF THE NASA GALILEO PROBE HEATSHIELD

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ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER
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Tests were conducted in a hypervelocity track facility to establish the ablative characteristics of the heatshield material for the NASA/Ames Galileo Probe. Data were obtained from eight shots at launch velocities ranging from 15,850 fps to 17,950 fps. Six of the shots were conducted through an argon environment. The test required the nosetip to be recovered intact. Measurements were made of the model velocity and in-flight surface temperature. A description of the test unit, test article, and test technique is presented herein.

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NOMENCLATURE

B	Bias contribution to uncertainty
P_d	Pressure in downrange portion of the range
P_u	Pressure in uprange portion of the range
S	Precision index
t_{95}	95th percentile point for the two-tailed Student's "t" distribution
U	Total uncertainty
V_i	Range entrance velocity

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC) at the request of the National Aeronautics and Space Administration (NASA/Ames Research Center) under Program Element 921E07, Control Number 9E07-00-0. The NASA project sponsor was Mr. Chul Park. The NASA project monitor was Mr. Charles DeRose. The results of the test program were obtained by ARO, Inc., AEDC Group (a Sverdrup Corporation Company), contract operator of AEDC, AFSC, Arnold Air Force Station, Tennessee, under ARO Project Number V41G-02.

Eight tests were conducted in the Hypervelocity Track G, von Karman Gas Dynamics Facility (VKF), AEDC, from October 14, 1980 through November 24, 1980. The objective of the test program was to launch and recover the carbon phenolic heatshield model after flight through an argon atmosphere.

A copy of the final data package for this test program has been transmitted to NASA/Ames, the sponsor of the test program. Requests for copies of the data should be addressed to NASA/ARC, Entry Technology Branch, Mail Stop 229-4, Moffett Field, CA 94035. A copy of the final data package is on file on microfilm at AEDC.

Presented in this report are descriptions of the test unit, including instrumentation, test procedure, data reduction technique, and data quality estimates. Sample experimental data are presented in the Appendix.

2.0 APPARATUS

2.1 TEST FACILITY

The VKF Hypervelocity Track G is described in detail in Ref. 1. The test facility consists of a launcher, a 1000-ft-long tank equipped with a track to guide the test projectile, and a recovery tube to recover the model after testing. A schematic of the test facility is shown in Fig. 1.

The launcher used was a 2.5-in.-caliber, two-stage, light gas gun approximately 150 ft long. The test chamber consists of a 10-ft-diam tank, 1000 ft long, which is divided into three sections. Each section can be maintained at any desired ambient pressure from one atmosphere down to a few millimeters of mercury. For these tests an argon environment was provided in the test chamber. The track, which consists of four rails inside a 7-in.-ID steel tube, guides the test model through the test chamber and into the recovery tube.

In the recovery tube, the test model energy is dissipated in the compression of a gas. The components of the recovery system are (1) a 30-ft section of converging rails to "guide" the projectile into the recovery tube, and (2) a 500-ft recovery tube composed of an assembly of 10-ft sections of 2.5-in.-ID by 4.5-in.-OD stainless steel tubing. The initial 50 ft of recovery tube extends into the test environment tank and is attached to the converging rail section.

2.2 TEST MODELS

The model design used for these tests is shown in Fig. 2. The nosetips were fabricated from a carbon phenolic 20° dixie-cup layup material. The model is comprised of an aluminum core, a Lexan® base, a heatshield, and the nosetip.

In addition to bonding with BA2112 epoxy, the nosetip specimens were mechanically anchored to the model body by four carbon-carbon pins placed 90° apart. The four pins were machined flush with the nosetip surface. The purpose of the carbon-carbon pins was to enhance the probability of nosetip recovery.

2.3 ARGON ENVIRONMENT

This test required an argon environment at 50 to 300 torr in the uprange section of the range for six of the eight shots. Air contamination of the argon environment was required to be less than 4 percent by volume. In order to provide this environment, the range was evacuated to approximately one torr of air and then filled to the desired pressure with argon. In order to insure the proper argon environment, gas samples were taken prior to each shot.

2.4 INSTRUMENTATION

The instrumentation used in this test included ten X-ray stations and six laser stations. These stations provided the necessary in-flight side view pictures, so that the nosetip characteristics could be monitored during flight. At three of the laser stations, oblique views were used to provide better nosetip surface viewpoints. Data from the X-ray and event time recording systems were used to determine the model position, orientation, and velocity.

Other instrumentation used on this test includes image-converter camera systems at various locations along the track. These cameras view the model nosetip from almost head-on and record the brightness temperature distribution on the nosetip. These camera installations are calibrated so that surface temperature distributions can be obtained from these photographs. Test environmental conditions at test time were measured by the pressure and temperature measurement systems. Table 1 lists the instrumentation locations used for these tests.

3.0 TEST DESCRIPTION

3.1 TEST PROCEDURE AND CONDITIONS

The test conditions for all shots are given in Table 2.

Prior to the launching of the model, the complete model assembly was dimensionally inspected. This procedure established the pretest nosetip configuration.

The model is accelerated to the desired velocity by the two-stage launcher and enters the blast tank. The function of the blast tank is to separate and contain the muzzle gases and prevent them from entering the range tank. The blast tank is separated from the range tank by a quick-operating valve which closes behind the model.

The test environment of interest is encountered in the uprange section of the range. In this test the test environment is that of argon. Throughout the flight, characteristics of the nosetip are monitored photographically.

The model then enters the downrange section of the range. The uprange and downrange sections are separated by a quick-acting valve so that a pressure differential can be maintained when desired.

At the end of the downrange section the model enters the recovery tube. The recovery tube is charged with staged pressures so that the model can be non-destructively decelerated to a stop. The recovery tube terminates into a tapered rail section which mechanically arrests the model and allows the nosetip to be recovered intact.

3.2 DATA REDUCTION

The model velocity history is obtained from the timing data recorded during the shot combined with the known instrumentation locations. Once the velocity history is known, other quantities of interest (e.g., drag coefficient, model ballistic coefficient, and average velocity) are computed.

The ablation characteristics of the nosetip, in this test, were to be determined by NASA/Ames.

3.3 DATA UNCERTAINTY

Measurement uncertainty is a combination of bias and precision errors defined as (Ref. 2):

$$U = \pm (B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation, and t_{95} is the 95th percentile point for the two-tailed student's "t" distribution , and depends on the sample size.

Estimates of the measured data uncertainties for this test are given in Table 3.

4.0 DATA PACKAGE PRESENTATION

The final data package for this project was prepared under separate cover. The package presents the data summarizing the test conditions and test results, including the test setup, test article information, and trajectory data. Pretest model photographs and prints of in-flight X-ray and laser photographs, along with nosetip surface temperature data, were transmitted to NASA/Ames during the test program. Recovered test specimens were returned to NASA/Ames at the conclusion of the test program. Sample data are included in the Appendix of this report.

5.0 REFERENCES

1. Test Facilities Handbook (Eleventh Edition), "von Karman Gas Gas Dynamics Facility, Vol. 3," Arnold Engineering Development Center, June 1979.

2. Abernathy, R. B. and Thompson, J. W., Jr., "Handbook of Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5, February 1973.

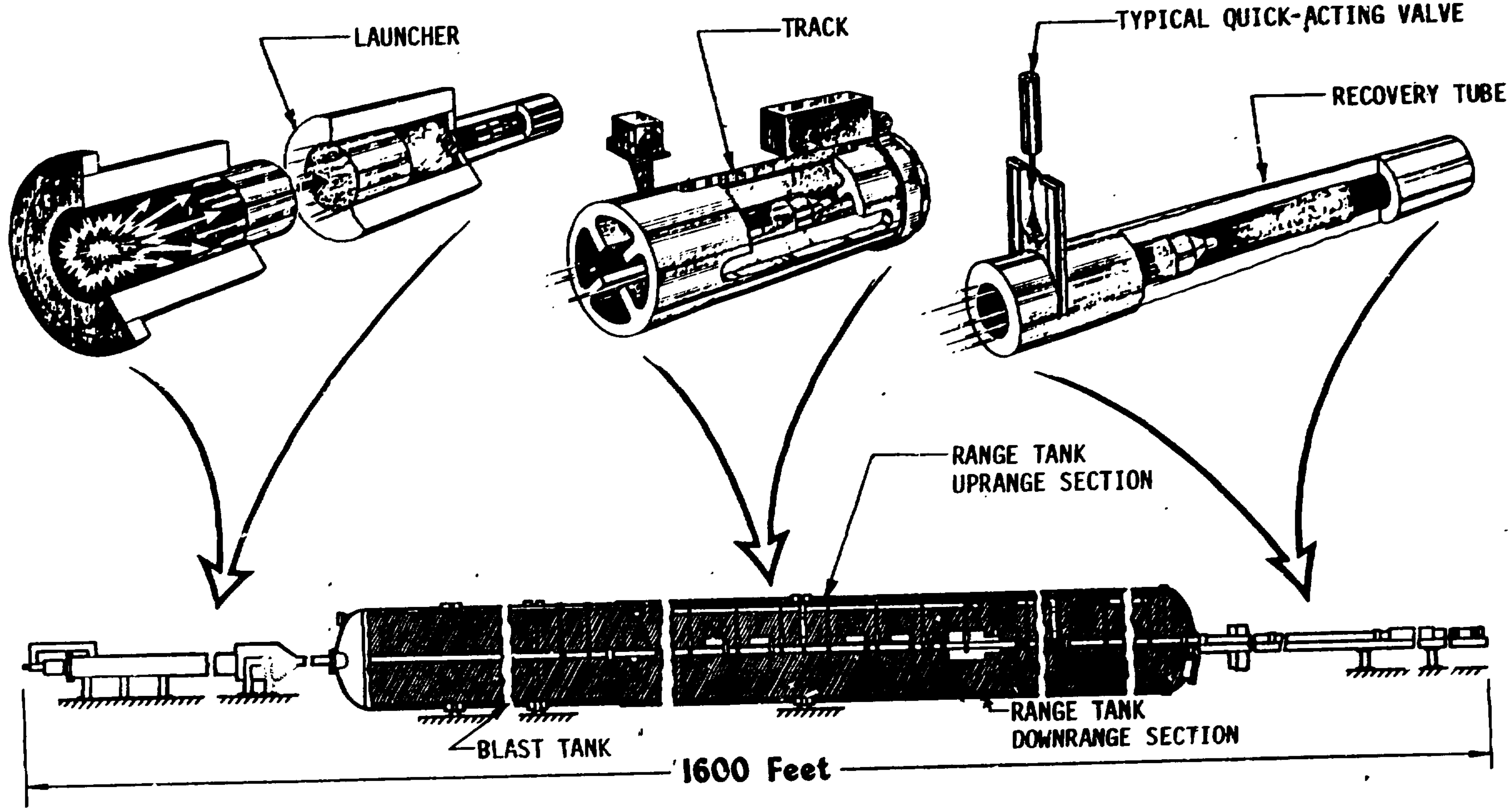

Figure 1. Hypervelocity Track G

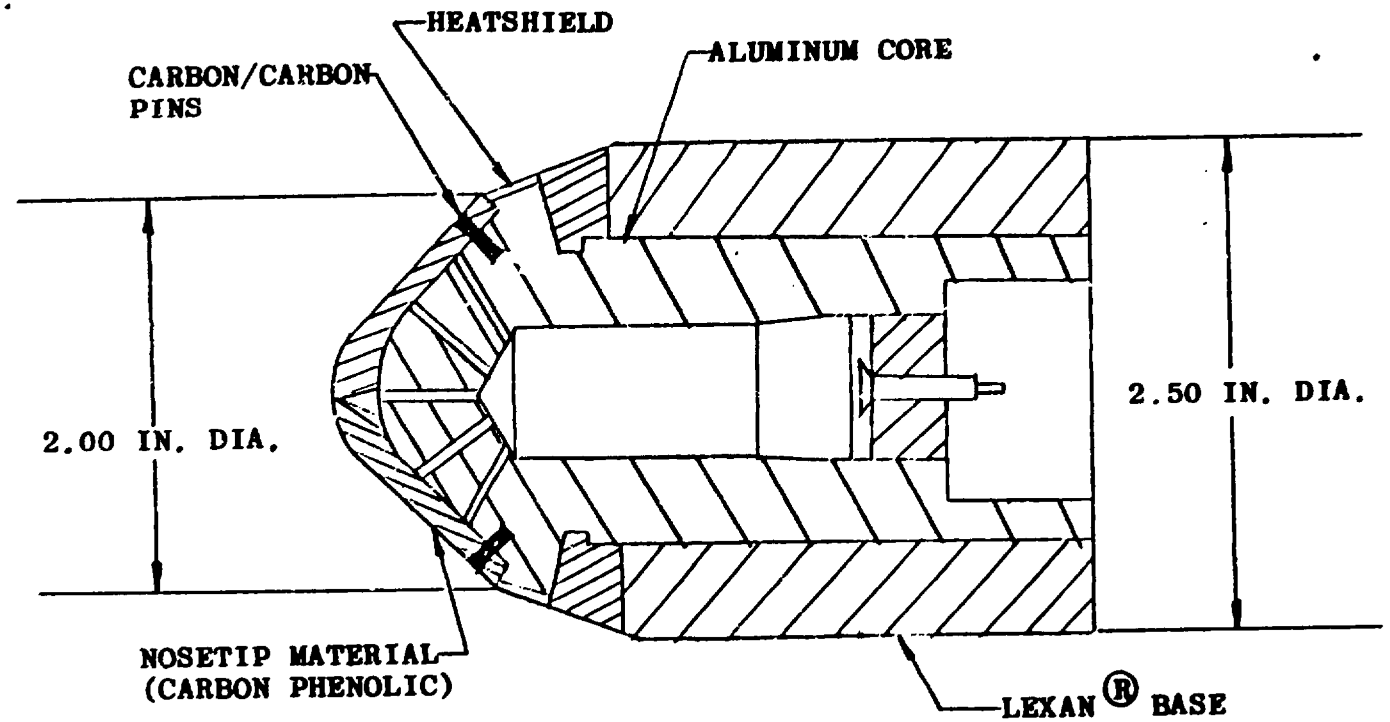

FIGURE 2. MODEL DRAWING

TABLE 1. TEST EQUIPMENT SETUP

Equipment Designation				Equipment Location
Range Reference	Laser	X-Ray	IC	Distance from Range Entrance, ft
Launcher Exit				-48.15
		X-A		-42.61
		X-B		-27.61
Range Entrance (QOV 1 & QOV 2)				0.0
		X-1		2.55
	L-2			52.86
		X-2		54.17
			IC-4	94.63
		X-7		150.92
		X-10		220.92
	L-11		IC-11	232.98
QOV-3				305.15
		X-15		312.67
		X-18		377.8
			IC-20	395.3
	L-19			398.11
		X-23		472.67
		X-28		577.80
			IC-29	591.48
	L-29			598.11
		X-34		697.8
	L-35			721.36
		X-40		817.80
	L-41			841.35
Recovery Tube Entrance				875.24
QOV-4				920.21

QOV = Quick-Operating Valve
IC = Image-Converter Camera

TABLE 2. TEST SUMMARY

Shot No.	Model No.	Vi (fps)	Pu (torr)	Pd (torr)	Nosetip Recovery	Remarks
5457	6450	15,850	104 (AR)	98 (air)	Yes	
5471	6494	17,020	152 (AR)	150 (air)	Yes	
5472	6495	17,950	54 (AR)	49 (air)	No	Failed in recovery
5473	6496	17,750	203 (AR)	200 (air)	Yes	
5474	6497	17,450	100 (air)	100 (air)	Yes	
5475	6498	17,800	302 (AR)	301 (air)	No	Failed in launch
5476	6499	17,620	300 (AR)	300 (air)	Yes	
5477	6500	17,820	299 (air)	300 (air)	Yes	

Table 3. Uncertainty in Test Parameters

Parameter Designation	Estimated Measurement: Precision Index (S): Percent of Reading	Precision Index (S): Unit of Measurement	Precision Index (S): Degree of Freedom	Bias (B) (1): Percent of Reading	Bias (B) (1): Unit of Measurement	Uncertainty ±(B + t_{95}S): Percent of Reading	Uncertainty ±(B + t_{95}S): Unit of Measurement	Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
Range Pressure	± 1		30	0		± 2		10 to 300 torr	Precision variable capacitive transducer	Remote null reading meter	Comparison with secondary standard
Model Velocity	± 0.0011		70	± 0.0034		± 0.0046		15000 to 19000 fps	Calculated from distance-time data		
Range Temperature		± 0.90	30		± 0.10		± 1.98	50 to 100 deg F	Thermocouple	Multipoint stripchart servopotentiometer	Comparison with secondary standard
Model Weight		± 1.0			0		± 2.042	400 to 600 gram	Laboratory pan scale	Handwritten from scale	Comparison with secondary standard
Specimen Weight		± 0.0012	30		0		± 0.0024	5 to 20 gram	Laboratory pan scale	Handwritten from scale	Comparison with secondary standard
Distance Downrange		± 0.0044	43		± 0.010		± 0.0188	0 to 840 ft	X-Ray shadowgraphs	Photographic film	Range survey
Time Intervals	± 0.0002	± 1X 10^{-7}	100		0	± 0.0004	± 2X 10^{-7}	0 to 0.080 sec	24-bit counter	Modcomp computer	Comparison with primary standard
Brightness Temperature (Gen I System)		± 40	5		± 25		± 130	1600 to 3300 Deg K	Photopyrometer	Photographic film	Comparison with secondary standard
Brightness Temperature (Gen II System)		± 40	5		± 25		± 130	1400 to 2000 Deg K	Photopyrometer	Photographic film	Comparison with secondary standard

(1) Listed bias estimates were assumed except for brightness temperatures.

APPENDIX A

REPRESENTATIVE DATA OBTAINED

The representative data shown include a sample position and velocity history (Table A-1). Figure A-1 shows a typical nosetip in-flight temperature distribution. Figure A-1 (a) shows the isothermal contours and the locations of the vertical and horizontal temperature scans which are shown respectively as Figure A-1 (b) and (c).

INITIAL CONDITIONS: WEIGHT=5.5600D 02GRAMS PINF= 1.039 02TORR TINF= 5.3244D 02DEG. R

DRAG COEFF= 8.4638D-01 BASE DIAMETER= 2.5000D 00INS. DELTA TIME=1.0000D-03SEC. FINAL TIME= 7.0000D-02

CONSTANT DRAG COEFF INITIAL VELOCITY= 1.5850D 04

SHOT 5457

TIME SEC.	DIST FT.	VEL FT./SEC.
0.0	0.0	1.585000D 04
1.000000D-03	1.585000D 01	1.580870D 04
2.000000D-03	3.165870D 01	1.576760D 04
3.000000D-03	4.742620D 01	1.572670D 04
4.000000D-03	6.315290D 01	1.568600D 04
5.000000D-03	7.883880D 01	1.564550D 04
6.000000D-03	9.448630D 01	1.560520D 04
7.000000D-03	1.100890D 02	1.556510D 04
8.000000D-03	1.256550D 02	1.552530D 04
9.000000D-03	1.411180D 02	1.548560D 04
1.000000D-02	1.566660D 02	1.544620D 04
1.100000D-02	1.721120D 02	1.540690D 04
1.200000D-02	1.875190D 02	1.536790D 04
1.300000D-02	2.028870D 02	1.532900D 04
1.400000D-02	2.182160D 02	1.529040D 04
1.500000D-02	2.335060D 02	1.525190D 04
1.600000D-02	2.487580D 02	1.521360D 04
1.700000D-02	2.639710D 02	1.517550D 04
1.800000D-02	2.791470D 02	1.513760D 04
1.900000D-02	2.942850D 02	1.509990D 04
1.970963D-02	3.050000D 02	1.507330D 04

SECOND LEVEL CONDITIONS: PI= 9.0200D 01

DRAG COEFF = 8.4638D-01 VELOCITY= 1.5073D 04

TIME SEC.	DIST FT.	VEL FT./SEC.
2.070960D-02	3.200730D 02	1.504770D 04
2.170963D-02	3.351210D 02	1.502210D 04
2.270963D-02	3.501430D 02	1.499670D 04
2.370963D-02	3.651400D 02	1.497130D 04
2.470963D-02	3.801110D 02	1.494600D 04
2.570963D-02	3.950570D 02	1.492080D 04
2.670963D-02	4.099780D 02	1.489570D 04
2.770963D-02	4.248740D 02	1.487070D 04
2.870960D-02	4.397440D 02	1.484570D 04
2.970963D-02	4.545900D 02	1.482090D 04
3.070960D-02	4.694110D 02	1.479610D 04
3.170963D-02	4.842070D 02	1.477140D 04
3.270963D-02	4.989780D 02	1.474680D 04
3.370963D-02	5.137250D 02	1.472220D 04
3.470963D-02	5.284470D 02	1.469780D 04
3.570963D-02	5.431450D 02	1.467340D 04
3.670963D-02	5.578190D 02	1.464910D 04
3.770963D-02	5.724680D 02	1.462490D 04
3.870963D-02	5.870930D 02	1.460080D 04
3.970963D-02	6.016940D 02	1.457680D 04
4.070960D-02	6.162700D 02	1.455280D 04
4.170963D-02	6.308230D 02	1.452890D 04
4.270963D-02	6.453520D 02	1.450510D 04
4.370963D-02	6.598570D 02	1.448130D 04
4.470963D-02	6.743380D 02	1.445770D 04
4.570960D-02	6.887960D 02	1.443410D 04
4.670960D-02	7.032300D 02	1.441060D 04
4.770963D-02	7.176410D 02	1.438720D 04
4.870963D-02	7.320280D 02	1.436380D 04
4.970963D-02	7.463920D 02	1.434050D 04
5.070963D-02	7.607320D 02	1.431730D 04
5.170963D-02	7.750500D 02	1.429420D 04
5.270963D-02	7.893460D 02	1.427120D 04
5.370963D-02	8.036150D 02	1.424820D 04
5.470960D-02	8.178630D 02	1.422530D 04
5.570963D-02	8.320890D 02	1.420250D 04
5.670963D-02	8.462910D 02	1.417970D 04
5.770963D-02	8.604710D 02	1.415700D 04
5.870963D-02	8.746280D 02	1.413440D 04
5.970963D-02	8.887620D 02	1.411190D 04
6.070960D-02	9.028740D 02	1.408940D 04
6.170963D-02	9.169630D 02	1.406700D 04
6.270963D-02	9.310300D 02	1.404470D 04
6.370963D-02	9.450750D 02	1.402240D 04
6.470963D-02	9.590980D 02	1.400030D 04
6.570963D-02	9.730980D 02	1.397810D 04
6.670963D-02	9.870760D 02	1.395610D 04
6.770963D-02	1.001030D 03	1.393410D 04
6.870963D-02	1.014970D 03	1.391220D 04
6.970963D-02	1.028880D 03	1.389040D 04

Table A-1.

Velocity and Position History

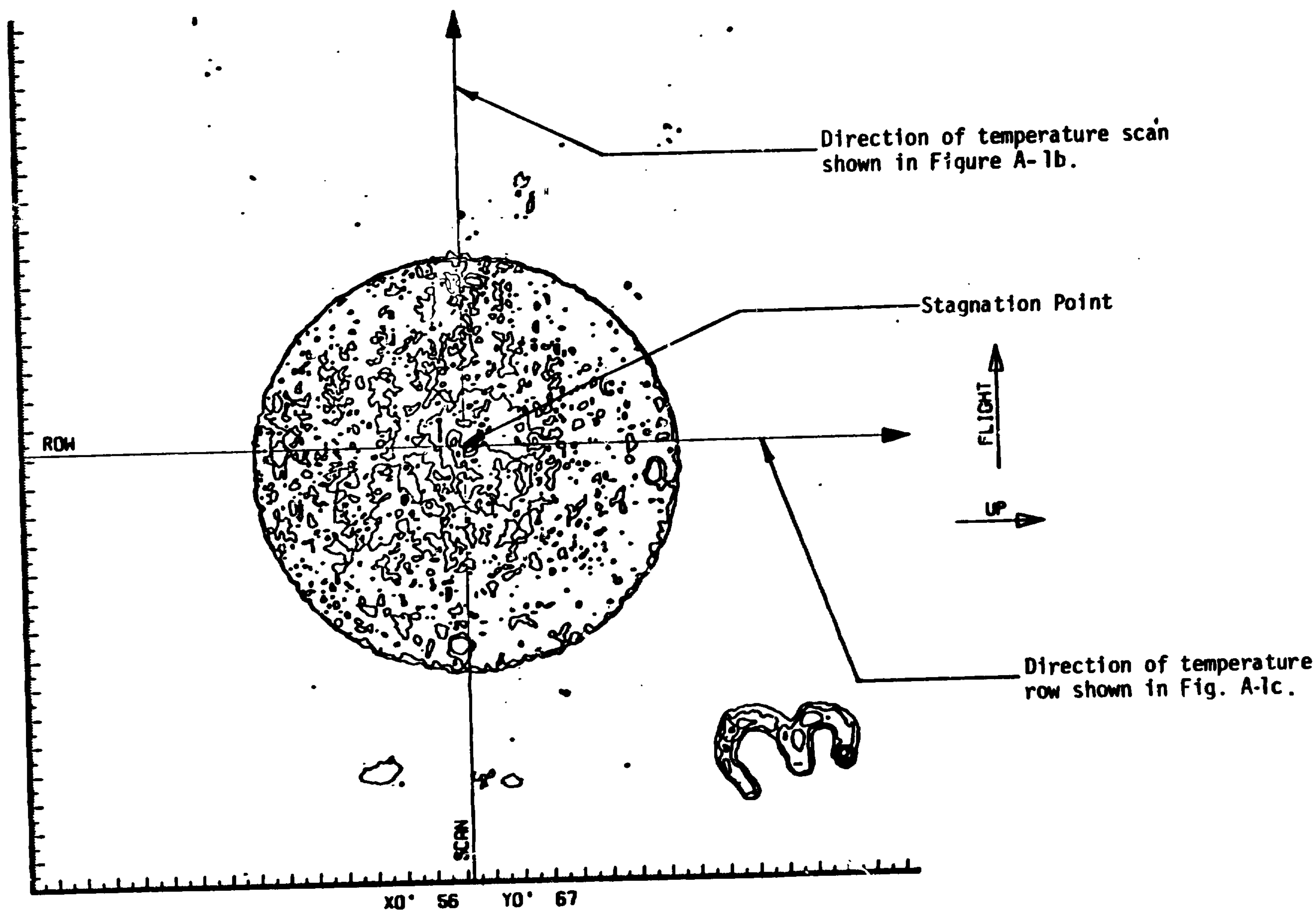

Figure A-1. In-Flight Surface Temperature Data
a. Isothermal contour

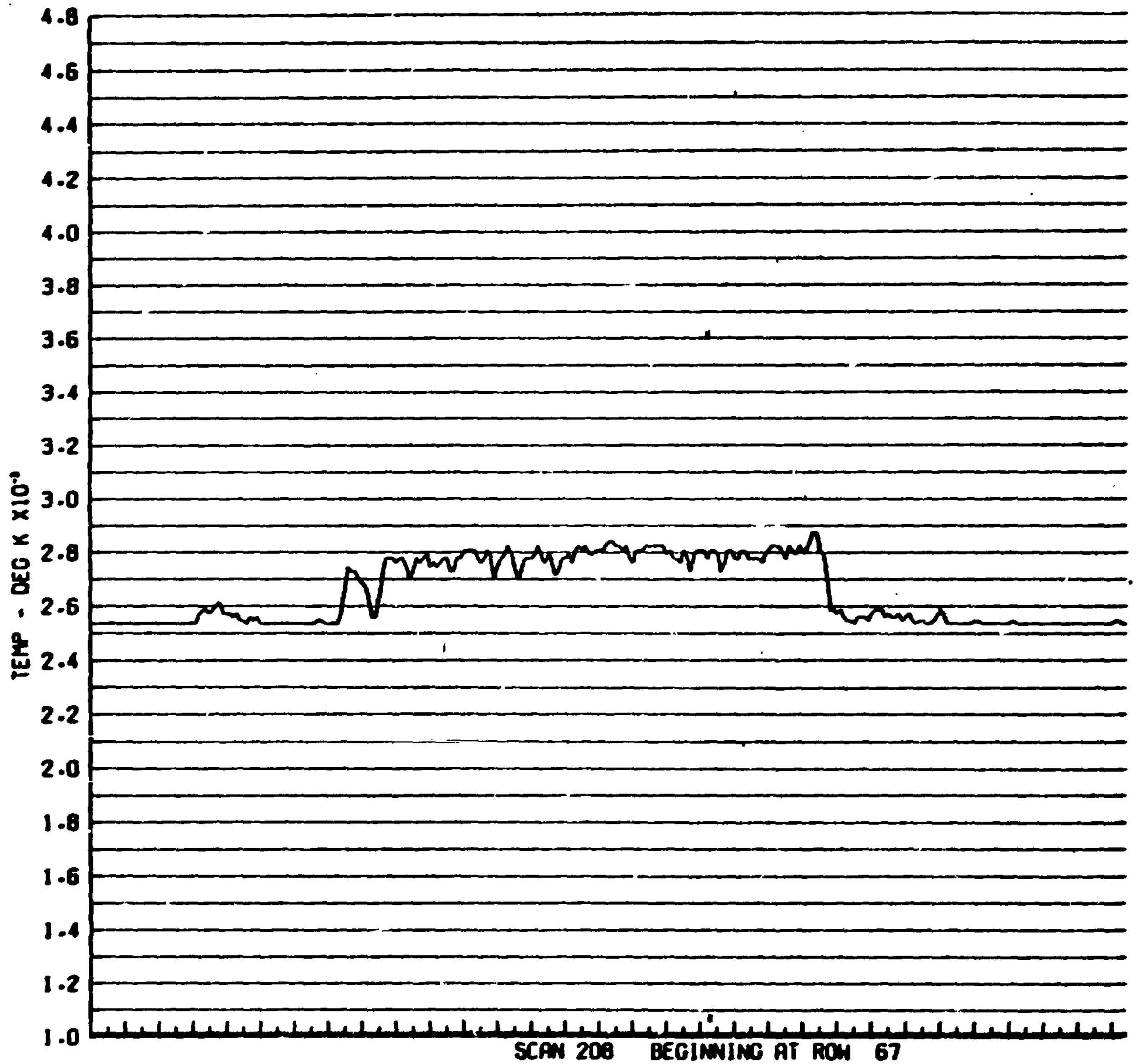

Figure A-1 Continued

b. Vertical temperature scan

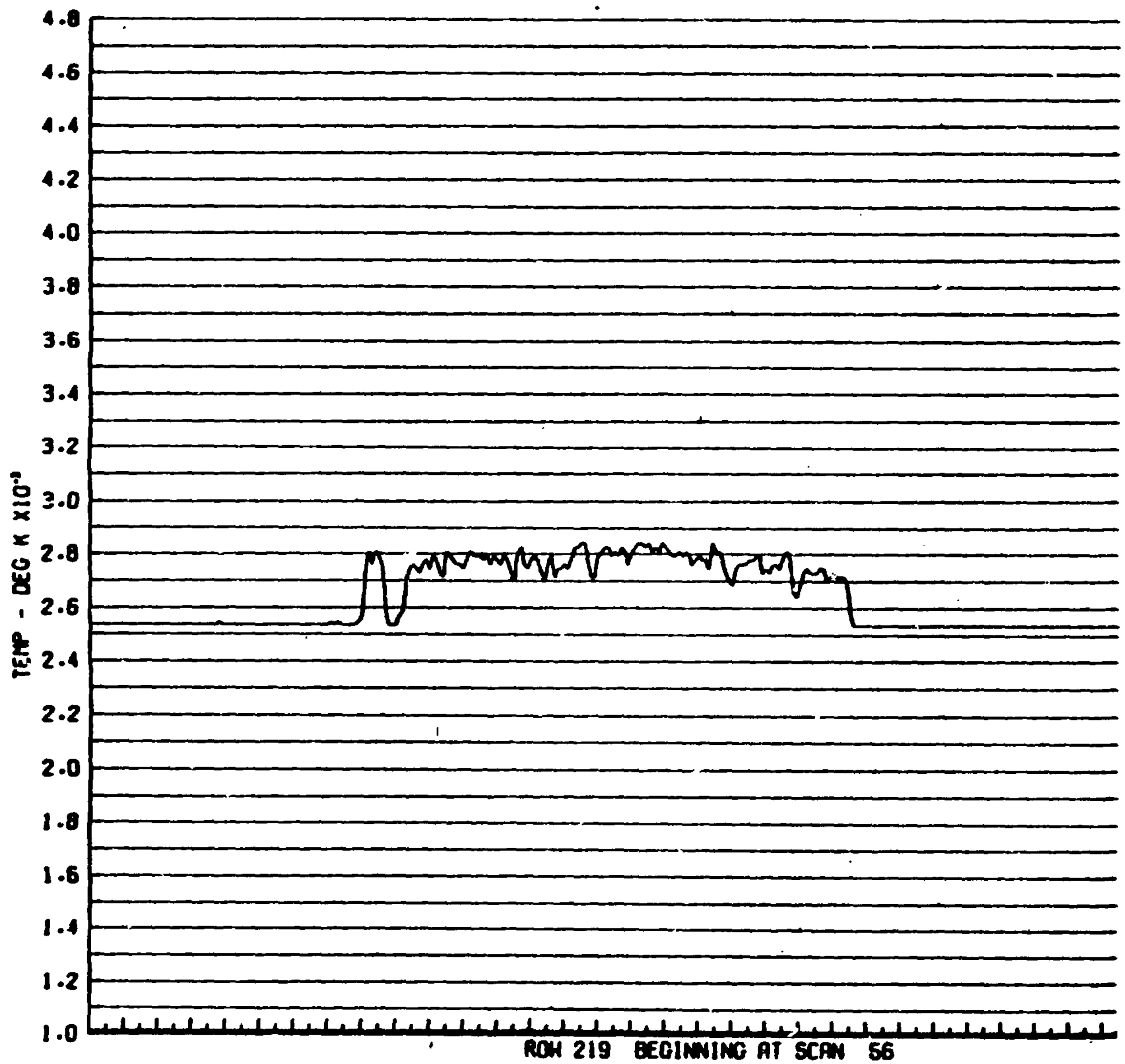

Figure A-1 Continued

c. Horizontal temperature row